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<p>Studies have been carried out to develop methods to couple Josephson junction oscillators at frequencies near 100GHz so as to demonstrate the feasibility of Josephson effect sources of reasonable power and impedance. Phase-locking of junctions separated by greater than a wavelength and coupled through microstrip line has been demonstrated and found in accord with theory. Forty junction arrays operating at 100GHz and 350GHz using this phase-locking scheme have been tested. Both series and parallel biasing of the junctions have been tested. It has been established that a total critical current spread of less than 10% is required for complete phase-locking with series bias. For parallel biased arrays with a critical current spread of 20%, all junctions locked in-phase providing coherent addition of power to the 20 Ohm load.</p>			
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MILLIMETER WAVE GENERATION USING JOSEPHSON JUNCTION ARRAYS

James Lukens  
Department of Physics  
State University of New York  
Stony Brook, New York 11794

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# Millimeter Wave Generation Using Josephson Junction Arrays

## Final Technical Report

Grant AFOSR 850205

### Statement of Work

- A) Methods will be studied to achieve coherence in large series biased arrays including resonantly coupled arrays.
- B) Fabrication techniques will be developed to make such large scale arrays.
- C) Measurements of the power and linewidth of mm wave Josephson radiation from these arrays will be made in order to determine the fundamental lower limits on radiation linewidth and the upper limits on radiated power.

Studies have been carried out to determine design parameters for distributed arrays of Josephson junctions to be used as spectrally pure sources near 100 GHz. Computer simulations have verified that proposed designs provide the required phase-locking and have determined the limits for the junction capacitance and the shunt inductance. The proper termination of the array transmission line to provide optimum phase-locking has been determined. Measurements have been made of the locking strength between two junctions coupled via a transmission line. Results are in agreement with predictions.

Work has been carried out in conjunction with NBS Boulder to test the suitability of conventional window junction fabrication technology for array sources. Several problems were revealed during these tests, including the difficulty of obtaining sufficiently low inductance shunt resistors. A technique was developed in this laboratory to fabricate

lead alloy junctions with low shunt resistance and inductance which are suitable for use in array sources.

Arrays of 40 junctions coupled via a  $20\ \Omega$  microstrip to an on chip  $20\ \Omega$  load have been tested. The design frequency was 100GHz. The power delivered to the load was monitored by measuring the rf current through the load using the amplitude of the Josephson step in a detector junction adjacent to the load resistor. All junctions of the array were biased in series with a common bias current. The results of phase-locking experiments show that if all the junctions of such an array are to phase-lock, a maximum spread of 10% in the junctions' critical currents can be tolerated. The measured critical current variation of the test array was about 20%.

The power delivered to the load was monitored as a function of the operating frequency of the array and exhibited a sharp peak at 109GHz, falling to zero several GHz on either side of this peak. The peak power detected corresponded to the coherent sum of the powers from 20% of the junctions in the array. The measured distribution of critical currents in the arrays together with the direct measure from the detector junction of the range of current over which a junction could phase-lock to the rf current in the microstrip showed that only 20% of the junctions in the array were phase locked at resonance. Thus the major conclusion of this work is that the microstrip coupling scheme developed does in fact correctly phase-lock distributed arrays of junctions such that the load power is the coherent in-phase sum of the available power from the individual junctions. In subsequent work, parallel biasing has been used to reduce the effective scatter in the critical currents and achieve a load power of  $1\mu\text{W}$ , which is the coherent sum of the power from all forty junctions in the array. This further demonstrates the claim for the proper operation of the phase-locking scheme developed.

In additional work carried out under this grant, an electron beam lithography system has been developed using equipment purchased with funding from an AFOSR URIP. Specifically, beam control and computer interface hardware have been designed and built to convert an AMRAY SEM into a vector EBL system controlled by an HP workstation computer. This system is designed to generate patterns with tens of nanometer resolution over centimeter fields as will ultimately be required for high-powered array sources. It includes the capability to register multilayer EBL patterns.

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J.E. Sauvageau, A.K. Jain, and J.E. Lukens, "Millimeter wave phase-locking in distributed Josephson arrays," *Int'l. J. of Infrared & Millimeter Waves*, 8, 1281 (1987).

J.E. Sauvageau, A.K. Jain, J.E. Lukens, and R.H. Ono, "Phase-locking in distributed arrays of Josephson oscillators," *IEEE Trans. on Mag.*, MAG-23, 1048 (1987).

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Personnel associated with Air Force Office of Scientific Research project  
AFOSR850205, MILLIMETER WAVE GENERATION  
USING JOSEPHSON JUNCTION ARRAYS  
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Paul G. Hicks, Student Research Aide

Daniel L. Hutton, Research Project Assistant

Aloke K. Jain, Post-doctoral Research Associate

James E. Lukens, Principal Investigator

Joseph L. Montani, Research Project Assistant

Amir Mortazawi, Research Project Assistant

Joseph E. Sauvageau, Research Project Assistant

Joseph Shortell, Student Research Aide

Audra Weiser, Assistant to Director

Roger M. Young, Research Project Assistant

# REPORT OF INVENTIONS AND SUBCONTRACTS

(Pursuant to "Patent Rights" Contract (Issue) (See Instructions on Reverse Side.)

1a NAME OF CONTRACTOR/ SUBCONTRACTOR		2a NAME OF GOVERNMENT PRIME CONTRACTOR		3 CONTRACT NUMBER		FORM APPROVED OMB NO. 0704-0016	
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5 "SUBJECT INVENTIONS" REQUIRED TO BE REPORTED BY CONTRACTOR/SUBCONTRACTOR (If "None", so state)		c DISCLOSURE NO., PATENT APPLICATION SERIAL NO. OR PATENT NO.		d ELECTION TO FILE PATENT APPLICATIONS		e CONFIRMATORY INSTRUMENT OR ASSIGNMENT FORWARDED TO CONTRACTING OFFICER			
b				UNITED STATES		FOREIGN			
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f EMPLOYER OF INVENTOR(S) NOT EMPLOYED BY CONTRACTOR/SUBCONTRACTOR		g ELECTED FOREIGN COUNTRIES IN WHICH A PATENT APPLICATION WILL BE FILED		h FOREIGN COUNTRIES OF PATENT APPLICATION					
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